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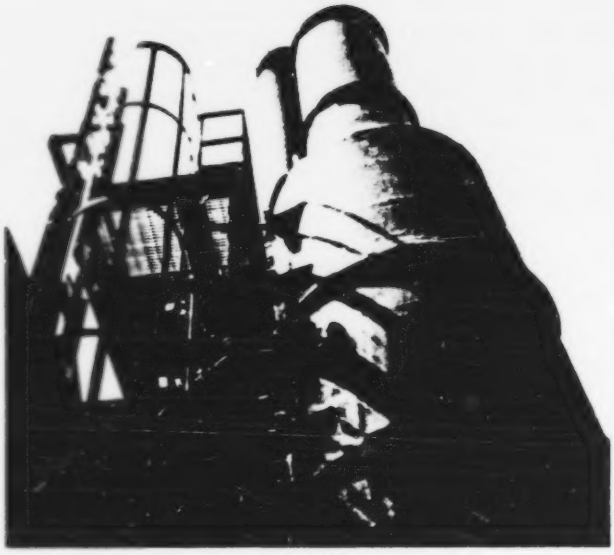

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DIRECT CONTACT FLUE GAS HEAT RECUPERATOR

CANADA PACKERS INC.

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MANITOBA/CANADA CONSERVATION AND RENEWABLE ENERGY DEMONSTRATION AGREEMENT

The availability of secure and affordable energy supplies is a subject of national concern. It is an accepted fact that our primary energy sources — oil and natural gas — are becoming less accessible and more costly. However, Canada is well-endowed with renewable and alternative resources that can provide a bridge into the future.

To this end, the governments of Manitoba and Canada entered into a Conservation and Renewable Energy Demonstration Agreement which was signed May 9, 1980 and terminated March 31, 1984. The Agreement was dedicated to the development and demonstration of conservation and renewable energy technologies. Equally cost-shared by the provincial and federal governments, the program had a total budget of $18-million.

The objectives of CREDA are:

- To develop and demonstrate promising new technologies, which, when widely adopted, will exploit renewable resources, conserve energy and/or use energy more efficiently.
- To develop broad public awareness of the potential of renewable energy and conservation technology.
- To provide opportunities for the commercial application of the technologies within Manitoba.
- To create economic spin-off benefits for manufacturing, industry and commerce.
- To create employment in new or existing energy-related industries.

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1.0 EXECUTIVE SUMMARY

Under the Canada/Manitoba Conservation and Renewable Energy Demonstration Agreement (CREDA), Canada Packers Inc. received funding to offset a portion of the capital costs for a novel boiler flue gas heat recovery system. This system, referred to as a "Direct Contact Heat Recuperator", was designed and manufactured by John Thurley Ltd. and was installed at Canada Packers' Winnipeg Packinghouse plant.

In contrast to conventional heat recovery systems, such as economizers and combustion air preheaters, the heat recuperator is capable of recovering up to four times more of the available waste heat from the flue gases. This is due to its ability to recover both the latent heat, by condensing the flue gas water vapour, and a greater portion of the sensible heat. As a result, the exit flue gas temperature is reduced to about $30^{o}C$.

Flue gas heat recuperators are ideally suited to operations which can make use of large quantities of hot water. Most food processing plants fall into this category. At Winnipeg Packinghouse, the recovered heat is transferred indirectly to the potable hot water heating system using a plate heat exchanger.

This report details the performance of the recuperator during its first year of operation. The monitoring results show that the average overall combustion efficiency of the boiler system was raised from 81.8 percent to 92.2 percent during winter operation, and 93.4 percent during summer operation. This improvement resulted in a first year fuel savings of 1,077,000 cubic metres of natural gas, a net cost reduction of $140,710.

During the start-up monitoring period, the recuperator was in operation an average of 86.2 percent of the time. In the first two months, winter conditions created freeze-up problems with the bypass damper. Thus, the initial utilization was about 60 percent. After this problem was solved, the utilization rate rose to a level of about 88 percent of the boiler operational time.

Overall, this project is considered to be very successful, both technically and financially. It is expected that the planned savings will be achieved.

For a total capital cost of $400,275, the simple payback is estimated to be 2.84 years, based on the first year operational savings.

RÉSUMÉ ADMINISTRATIF

En vertu de l'Entente Canada-Manitoba de démonstration des énergies renouvelables et des économies d'énergie (DEREE), la Canada Packers Inc. a bénéficié d'une subvention lui permettant d'amortir partiellement le coût d'installation d'un nouveau système de chaudière à récupération de la chaleur des gaz de combustion. Appelé "récupérateur de chaleur à contact direct", ce système a été conçu et manufacturé par la compagnie John Thurley Ltd. qui se chargea de l'installer dans la fabrique de conserves de la Canada Packers à Winnipeg.

À l'encontre des systèmes ordinaires de récupération de la chaleur comme les économiseurs et les réchauffeurs d'air comburant, le récupérateur de chaleur est capable de récupérer quatre fois plus de chaleur provenant des gaz de combustion. Cela est dû à la double propriété de pouvoir récupérer, d'une part, la chaleur latente, par condensation de la vapeur d'eau et, d'autre part, une plus grande partie de la chaleur sensible. Par suite, la température des gaz de combustion à la sortie est réduite à 30° C.

Les récupérateurs de chaleur peuvent être utilisés de manière idéale lorsque de grandes quantités d'eau chaude sont disponibles. C'est le cas de la plupart des usines de transformation des aliments. Dans l'usine winnipégoise de la Canada Packers, la chaleur récupérée est transférée indirectement au système de chauffage d'eau potable au moyen d'un échangeur de chaleur à plaque.

Le présent rapport fournit les détails du rendement du récupérateur au cours de la première année de fonctionnement. En ce qui concerne la chaudière, les résultats du contrôle indiquent qu'en général le rendement moyen de combustion est passé de 81,8 % à 92,2 % pendant l'hiver et à 93,4 % pendant l'été. Grâce à cette amélioration, la consommation de gaz naturel a été réduite de 1 077 000 mètres cubes, soit une économie de 140 710 $.

Pendant la période de contrôle initiale, le récupérateur ne fonctionnait en moyenne que 86,2 % du temps. Au cours des deux premiers mois, le froid hivernal a causé des problèmes de gel dans le registre de dérivation. Au début, le pourcentage d'utilisation n'était que de 60 %. Mais une fois ce problème résolu, le taux d'utilisation a atteint environ 88 % du temps de fonctionnement de la chaudière.

Dans l'ensemble, ce projet a été couronné de succès, tant du point de vue technique que financier. Selon nos prévisions, les économies prévues seront réalisées.

Pour un coût en capital global de 400 275 $, on prévoit une période de récupération simple de 2,84 années, en se fondant sur les économies d'exploitation réalisées pendant la première année.

2.0 INTRODUCTION

In the summer of 1982, Canada Packers Inc. installed a Direct Contact Heat Recuperator to recover waste heat from the boilers at its Winnipeg Packinghouse plant. The unit was designed by John Thurley Ltd. of Harrogate, England, and components were manufactured in Canada. Installation was carried out by Winnipeg's Engineering Department under the direction of Mr. J. Magro.

The heat recuperator can recover up to four times the heat recovered by conventional heat recovery systems. This is primarily due to its ability to condense the water vapour in the flue gas, thereby releasing its latent heat of vapourization. Also, the sensible heat recovery is greater than that of conventional systems. The flue gas exits the recuperator at temperatures as low as 30°C.

Basically, the recuperator is a heat exchanger that transfers heat from the flue gas by means of direct contact with water sprays. The heated water is then collected and pumped through a plate heat exchanger which transfers the heat to plant process water.

The $400,275 cost of the project was partially offset by a $180,592 contribution from the Manitoba/Canada Conservation and Renewable Energy Demonstration program.

3.0 BACKGROUND

Until recently, the amount of heat that could be recovered from a boiler's flue gases was limited by the requirement that they not be cooled below about 150°C in order to prevent condensation of water vapour and various acidic compounds. This was done to prevent corrosion problems from occuring in the boiler's breeching and stack as well as the heat recovery equipment.

The potential fuel cost savings from recovering more of the waste heat were not sufficient to justify the extra cost for larger heat transfer surfaces and more extensive use of corrosion resistant materials.

3.1 CONVENTIONAL FLUE GAS HEAT RECOVERY SYSTEMS

Conventional flue gas heat recovery systems are either economizers or combustion air preheaters.

An economizer is an air-to-liquid heat exchanger used to preheat boiler feedwater. It usually consists of an arrangement of finned tubes located in the boiler's stack, through which the feedwater flows.

In order to prevent corrosion problems due to condensation of water vapour and acids, the flue gas temperature must be maintained above 150°C. Feedwater provides a simple answer to this consideration since it normally enters the economizer at a temperature above 100°C, which is sufficient to maintain the external surface temperature of the heat exchange tubes above 150°C. This simple control scheme depends on maintaining a balance between the flue gas and feedwater flow rates. During periods of low boiler firing rate, the flue gas flow rate drops, causing an imbalance which results in a decrease in the flue gas temperature leaving the economizer. In order to prevent the temperature from dropping below the condensation point,

3.1 CONVENTIONAL FLUE GAS HEAT RECOVERY SYSTEMS (continued)

automatic systems can be installed to bypass the economizer or to raise the temperature of the feedwater entering the economizer.

A combustion air preheater is an air to air heat exchanger. It saves fuel by preheating the air used to sustain combustion.

One type of air preheater is called a recuperator. It usually consists of a plate heat exchanger with the flue gas and combustion air flowing on opposite sides of the plate. Another type of preheater, called a regenerator, transfers heat by alternately exposing a thermal storage mass to the flue gas and the combustion air. A very common type of regenerator is the heat wheel. It consists of a rotating mass, half of which is in the flue gas stream while the other is in the combustion air stream.

In order to prevent condensation, proper sizing of an air preheater is necessary. At low firing rates it may be necessary to bypass the preheater in order to maintain the flue gas temperature above 150°C.

Although they have some limitations, economizers and air preheaters have proven to be very practical devices over many years. They can improve the overall boiler combustion efficiency to as much as 85 percent.

TABLE I

PERFORMANCE OF CONVENTIONAL vs. CONDENSING HEAT RECOVERY SYSTEMS

Heat Recovery System	Exit Flue Gas Temperature	Overall Combustion Efficiency (1)	Heat Recovery Rate (2)	
			% Fuel Input	% Waste Heat
None	238°C	80.0%	0.0	0.0
Conventional	150°C	84.1%	4.1	20.5
Condensing	30°C	96.3%	16.3	81.5

(1) Assuming 25 present excess air.

(2) Assuming no losses in heat recovery system.

3.2 CONDENSING HEAT RECOVERY SYSTEMS

Today's high fuel prices have prompted several companies to address the potential to economically recover more of the heat from boiler flue gases. This has resulted in the development of condensing heat recovery systems, which are capable of recovering up to four times as much heat as conventional economizers and air preheaters. This vast improvement in performance has been achieved as follows. First, most of the sensible heat is recovered from the flue gases by cooling them to an exit temperature of 30°C or less. This low flue gas temperature in turn causes the water vapour to condense from the flue gas and release its latent heat of vapourization which can then also be recovered.

Table I shows an example of the potential improvement in performance of condensing heat recovery systems compared with conventional systems. The condensing system can recover nearly four times as much heat as the conventional system. This improves the overall combustion efficiency to 96.3 percent compared to 84.1 percent with a conventional system.

Although they can recover much more heat than conventional systems, condensing heat recovery systems are also much more costly. There are several reasons for this. Condensing systems tend to be physically larger than conventional systens in order to provide extra heat transfer surface. They also require the extensive use of corrosion resistant materials due to the condensing of acidic compounds with the water vapour. Finally, condensing systems can be more complex than conventional systems, requiring auxiliary equipment such as pumps and fans and more sophisticated controls.

Whether or not the extra cost of a condensing heat recovery system can be justified, depends largely on the price of fuel, which varies widely across Canada. Therefore each potential installation should be evaluated separately.

3.3 APPLICATION OF CONDENSING HEAT RECOVERY AT THE WINNIPEG PACKINGHOUSE

In 1981, various flue gas heat recovery systems were considered for the three boilers at the Winnipeg packinghouse plant. Among them were condensing heat recovery systems designed to preheat water for use in processing and sanitation as well as for boiler feed. A study of the plant's daily and seasonal steam and hot water production profile confirmed that the cost of recovering the additional heat could be justified.

A condensing heat recovery system designed and manufactured by John Thurley Ltd., and called a Direct Contact Heat Recuperator was selected. Due to the technical risks associated with applying new technology, and the longer payback period for the recuperator compared to an economizer, a proposal was made to demonstrate the technology under the Manitoba/Canada Conservation and Renewable Demonstration Program. This proposal was approved in the fall of 1981.

The Direct Contact Heat Recuperator was installed during the summer of 1982. The remainder of this report documents the first six months' performance of the unit.

4.0 DIRECT CONTACT HEAT RECUPERATOR

In the summer of 1982, a heat recuperator designed and manufactured by John Thurley Ltd., was installed at the Winnipeg Packinghouse plant. This system recovers waste heat from the flue gases of the three steam boilers.

4.1 PRINCIPLE OF OPERATION

The Thurley recuperator recovers heat from flue gases by bringing them into direct contact with cold water sprays. The cold sprays are essential to achieving the recuperator's high rate of heat recovery. They cause the water vapour in the flue gas to condense, thereby releasing its latent heat of vapourization to the water spray. The latent heat provides approximately half of the heat recovered by the recuperator. The remainder is due to sensible heat transfer.

The recuperator produces water at a temperature of approximately 54°C. The water is passed through a plate heat exchanger to heat potable process water. The flue gases leave the recuperator at a temperature of 38°C or less, thereby raising the overall combustion efficiency to in excess of
96 percent.

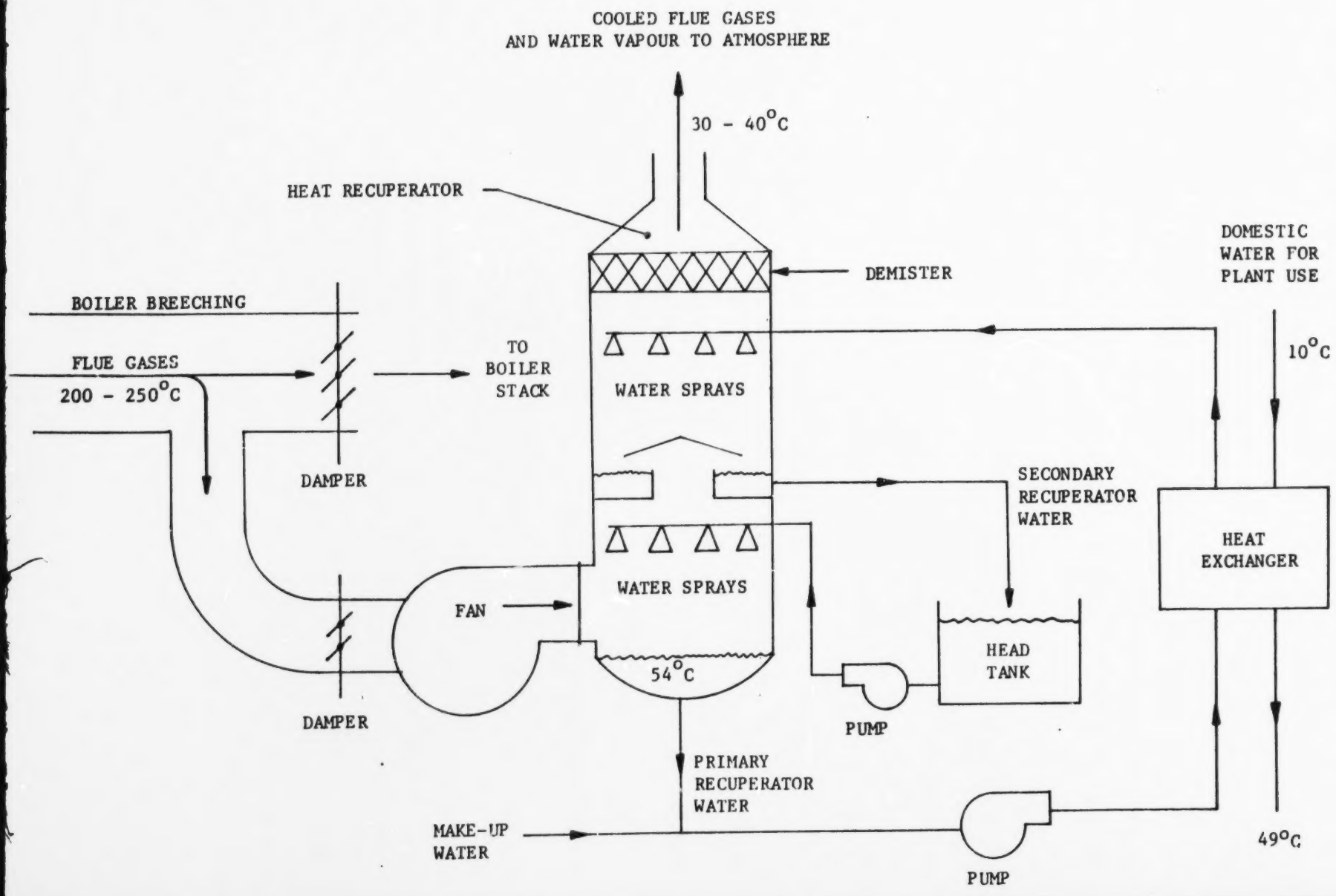
The Thurley recuperator is ideal for operations which can make use of large quantities of hot water. Many companies in the Food and Beverage sector fall into this category because of their need for hot water for processing and sanitation. The heat can also be used to preheat boiler make-up water.

4.2 DESCRIPTION OF RECUPERATOR

A schematic diagram of the heat recuperator is shown in Figure 1. The recuperator consists of two sections. The lower section, incorporates the flue gas inlet and quench zone and the upper section houses the demister and the flue gas outlet.

During operation, the flue gas bypasses the existing boiler stack and is forced through the recuperator by means of an induced draft fan. A recirculating water loop transfers heat from the flue gas to cold, potable water via a plate heat exchanger. This heated water (49°C) is then further heated with live steam to be used for plant processes, sanitation and as boiler make-up.

FIG. 1. THURLEY DIRECT CONTACT RECUPERATOR



4.2 DESCRIPTION OF RECUPERATOR (continued)

Recirculating water cooled in the plate heat exchanger is sprayed into the upper contact section of the recuperator and collected on a stainless steel baffle plate. This partially heated water is then run off to a head tank, from which it is pumped to the sprays of the lower quench section. After collection in the base of the recuperator it is then pumped back to the plate heat exchanger, which completes the loop.

Direct contact with acidic compounds in the flue gas causes the recirculating water to become acidic. Furthermore, recirculation causes the acids to concentrate, thereby continuously reducing the pH. This effect is partially countered by adding make-up water at the head tank to dilute the acid, and maintain the pH above 4. This minimizes the acidity but does not eliminate it, therefore corrosion resistant materials have been used throughout the recuperator. Stainless steel has been used in the components located in the lower section, which have the most contact with the recirculating water. The stack and flue gas outlet have been con- structed of fibreglass reinforced plastic.

The recirculating water flow rate can be manually or automatically controlled in order to maintain a maximum temperature of 54°C in the base of the recuperator. To maintain efficient spray contact action and quenching, the water flow rate is maintained above a minimum allowable level. Thus, under conditions of reduced boiler load, a lower recirculating water temperature will result, but the heat recovery efficiency will, however, be maintained.

5.0 HEAT RECUPERATOR PERFORMANCE

5.1 RECUPERATOR UTILIZATION

In order to maximize the savings, it is necessary to maximize the utilization (operating hours) of the recuperator.

Each shift, the stationary engineer reads an elapsed time meter and records the number of recuperator operating hours, along with the reaons for any down-time. This information has been valuable to the project engineer in identifying and solving problems.

The utilization rate is shown in Tables 2 and 3. It has been expressed in hours per week and as a percent of the maximum possible hours (168). The recuperator operated during 86.4 percent of the boiler operating hours in the first monitoring period (Table 1). The utilization would have been nearly 100 percent of the boiler operating hours except for start-up related problems during the first two months of operation. The boilers operated continuously during the entire period, therefore the utilization was also 86.4 percent of the total available time.

During the second monitoring period the recuperator was utilized 87.8 percent of the boiler operating hours and 78.7 percent of the total available hours (Table 2). This period coincided with the end of the heating season and most of the non-heating season. Steam was not required for space heating, therefore the boilers were shut down during non-production periods, mainly weekends. This reduced the total available operating time for the recuperator. There were other periods, also usually during weekends, when the demand for hot water was insufficient to justify operation of the recuperator even though the boilers were in operation. During production days the recuperator operated nearly 100 percent of the time.

5.2 HEAT RECOVERY RATE

The amount of heat recovered is measured by a meter which records the heat transferred from the recuperator water to the plant water in the plate heat exchanger. This data is used to calculate the heat recovery as an hourly rate and as a percentage of the boiler fuel input, as shown in Tables 2 and 3. The latter figure is a good indicator of the recuperator's heat recovery performance.

The recuperator recovered 10.4% of the fuel input to the boilers during the first monitoring period (Table 1), and 11.6% in the second period (Table 2). The slight increase in the second period was not due to an improvement in the heat recovery efficiency of the equipment, but was related to the procedure of week-end boiler shutdown practised during that period. The demand for hot water was always lowest on weekends, therefore the heat recovery rate was lower on weekends than on weekdays. The average weekly heat recovery rate was lower in the first period because weekend operation was included.

The heat recovery efficiency of the recuperator averages approximately 70%, which is considered to be good performance for any heat recovery system.

TABLE 2 - RECUPERATOR PERFORMANCE

FIRST MONITORING PERIOD, OCTOBER, 1982 - MARCH, 1983

Week		Boiler Operation	Recuperator Utilization			Boiler Fuel Input (1)	Heat Recovery Rate		
				% of	% of		Total	Ave.(2)	Fuel Input
		h	h	Boiler	Week	GJ/h	GJ	GJ/h	%
Oct.	2	168	117	69.6	69.6	n/a	559	4.78	n/a
	9	168	37	22.0	22.0	37.7	156	4.22	11.2
	16	168	94	56.0	56.0	n/a	373	3.97	n/a
	23	168	144	85.7	85.7	40.0	705	4.90	12.2
	30	168	119	70.8	70.8	44.5	566	4.76	10.7
Nov.	6	168	120	71.4	71.4	42.2	502	4.18	9.9
	13	168	113.5	67.6	67.6	41.0	550	4.85	11.8
	20	168	167.5	99.7	99.7	43.2	778	4.64	10.8
	27	168	168	100.0	100.0	41.7	701	4.17	10.0
Dec.	4	168	150	89.3	89.3	42.4	647	4.31	10.2
	11	168	108	64.3	64.3	49.4	559	5.18	10.5
	18	168	150.5	89.6	89.6	42.4	507	3.37	7.9
	25	168	145	86.3	86.3	35.3	468	3.23	9.1
Jan.	1	168	168	100.0	100.0	41.3	702	4.18	10.1
	8	168	140	83.3	83.3	51.9	535	3.82	7.4
	15	168	168	100.0	100.0	47.2	759	4.52	9.6
	22	168	168	100.0	100.0	45.7	838	4.99	10.9
	29	168	166.5	99.0	99.0	44.3	858	5.15	11.6
Feb.	5	168	168	100.0	100.0	42.3	794	4.73	11.2
	12	168	160	95.0	95.0	40.3	836	5.23	13.0
	19	168	168	100.0	100.0	40.8	839	4.99	12.2
	26	168	168	100.0	100.0	38.0	727	4.33	11.4
Mar.	5	168	162	96.4	96.4	41.8	675	4.17	10.0
	12	168	168	100.0	100.0	38.6	655	3.90	10.1
	19	168	166	98.8	98.8	40.8	664	4.00	9.8
	26	168	168	100.0	100.0	35.7	536	3.19	8.9
		4,368	3,772	86.4	86.4	42.0	16,489	4.38	10.4

(1) During boiler operating hours
(2) During recuperator operating hours.

TABLE 3 - RECUPERATOR PERFORMANCE

SECOND MONITORING PERIOD, APRIL - SEPTEMBER, 1983

Week		Boiler Operation	Recuperator Utilization			Boiler Fuel Input (1)	Heat Recovery Rate		
				% of	% of		Total	Ave.(2)	Fuel Input
		h	h	Boiler	Week	GJ/h	GJ	GJ/h	%
Apr.	2	168	162	96.4	96.4	37.0	500	3.09	8.4
	9	168	166	98.8	98.8	38.0	640	3.86	10.2
	16	168	168	100.0	100.0	35.1	614	3.65	10.4
	23	133	133	100.0	79.2	32.3	480	3.61	11.2
	30	168	142	86.9	86.9	33.6	486	3.33	9.9
May	7	168	143	85.1	85.1	33.0	572	4.00	12.1
	14	168	148	88.1	88.1	34.1	604	4.08	12.0
	21	152	124	81.6	73.8	28.7	414	3.35	11.7
	28	147	125	84.4	74.4	31.5	494	3.95	12.5
June	4	142	128	90.1	76.2	32.6	521	4.09	12.5
	11	137	124	90.5	73.8	34.5	473	3.81	11.0
	18	151	121	80.1	72.0	32.8	372	3.07	9.4
	25	146	141	96.6	83.9	27.1	499	3.54	13.1
July	2	132	113	85.6	67.3	31.5	520	4.60	14.6
	9	168	124	73.8	73.8	27.2	474	3.82	14.0
	16	168	134	79.8	79.8	27.5	489	3.65	13.3
	23	140	135	96.4	80.4	30.4	484	3.59	11.8
	30	144	115	79.9	68.5	24.0	354	3.08	12.8
Aug.	6	145	126	86.9	75.0	29.6	427	3.40	11.5
	13	132	125	94.7	74.4	30.8	430	3.44	11.2
	20	142	119	83.8	70.8	29.1	433	3.64	12.5
	27	144	120	83.3	71.4	29.0	408	3.41	11.8
Sept.	3	134	105	78.4	62.5	28.3	345	3.29	11.6
		3,465	3,041	87.8	78.7	31.3	11,033	3.63	11.6

(1) During boiler operating hours.
(2) During recuperator operating hours.

5.3 REDUCTION IN STEAM AND FUEL USE

Table 4 shows that 626,000 m^3 of natural gas were saved in the first six month monitoring period. In order to arrive at this estimate the following factors were applied to the gross heat of 16,489 GJ recovered (Table 2).

5.3.1. CORRECTION FOR OUTDOOR STORAGE TANK LOSSES

A portion of the water heated by the recuperator on the night shift and on weekends is stored in a 21,200 m^3 outdoor tank. It has been estimated that 10% of the weekly heat recovered is lost due to the heat losses in the tank. Therefore the net heat recovered has been calculated to be 90% of the gross.

5.3.2. STEAM SAVINGS FACTOR

The net heat recovered replaces heat which would otherwise have been obtained from steam. As shown in Appendix A, an average of 0.5198 t of steam are saved for every gigajoule of heat recovered. Therefore the steam saving is obtained by applying the factor to the net heat recovered.

5.3.3 FUEL TO STEAM RATIO

The fuel savings depend on the steam savings and efficiency of the boilers. The boiler efficiency can be accurately taken into account by using the fuel to steam ratio. The ratio is calculated each week from the metered fuel and steam consumption data and applied to the steam savings to obtain the fuel savings.

TABLE 4 - REDUCTION IN STEAM AND FUEL USE

MONITORING PERIOD, OCTOBER, 1982 - MARCH, 1983

Week		Gross Heat Recovered	Outdoor Storage Loss Factor	Net Heat Recovered	Steam Savings Factor	Steam Savings	Fuel to Steam Ratio	Fuel Savings
		GJ		GJ	t/GJ	t	m^3/t	m^3
Oct.	2	559	0.9	503	0.5198	262	80.8	21,200
	9	156	0.9	140	0.5198	73	80.8	5,900
	16	373	0.9	336	0.5198	175	80.8	14,100
	23	705	0.9	635	0.5198	330	81.1	26,800
	30	566	0.9	509	0.5198	265	81.1	21,500
Nov.	6	502	0.9	452	0.5198	235	81.1	19,100
	13	550	0.9	495	0.5198	257	81.1	20,800
	20	778	0.9	700	0.5198	364	81.1	29,500
	27	701	0.9	631	0.5198	328	82.7	27,100
Dec.	4	647	0.9	582	0.5198	303	82.7	25,000
	11	559	0.9	503	0.5198	262	82.7	21,700
	18	507	0.9	456	0.5198	237	80.6	19,100
	25	468	0.9	421	0.5198	219	81.0	17,700
Jan.	1	702	0.9	632	0.5198	329	83.3	27,400
	8	535	0.9	482	0.5198	251	81.3	20,400
	15	759	0.9	683	0.5198	355	83.5	29,600
	22	838	0.9	754	0.5198	392	82.6	32,400
	29	858	0.9	772	0.5198	401	81.4	32,600
Feb.	5	794	0.9	715	0.5198	372	78.1	29,100
	12	836	0.9	752	0.5198	391	82.8	32,400
	19	839	0.9	755	0.5198	393	82.8	32,600
	26	727	0.9	654	0.5198	340	77.5	26,300
Mar.	5	675	0.9	608	0.5198	316	78.5	24,800
	12	655	0.9	590	0.5198	307	77.1	23,700
	19	664	0.9	598	0.5198	311	80.9	25,200
	26	536	0.9	482	0.5198	251	79.7	20,000
						7,719		626,000

The gross heat recovery during the second monitoring period was 11033 GJ (Table 3). Allowing 10% for storage losses, the estimated net recovery was 9930 GJ.

Thus, the estimated steam reduction was:

= 9930 GJ x 0.5198 t/GJ

= 5160 t

The boilers' overall natural gas to steam ratio was 77.4 m^3/t during the second monitoring period, therefore the estimated fuel reduction was:

= 5160 t x 77.4 m^3t

= 399,000 m^3 of natural gas

5.4 ENERGY FOR AUXILIARY EQUIPMENT

The heat recovery system contains 82.9 kV·A of auxiliaries. The recuperator normally operates 24 hours per day, therefore the peak demand for power has increased by 82.9 kV·A.

The recuperator operated for 3772 hours during the monitoring period at an estimated power factor of 90 percent.

Therefore the energy consumption was:

Energy = 82.9 kV.A x 3772 h x 0.9 W/(V.A)

= 281,429 kW.h

= 1,013 GJ

Similarly in the second period, assuming pro-rated total operating hours for a full six months operation of 26/23 x 3041 hours:

Energy = 82.9 kV.A x 0.9 W/(V.A) x 3041 h x 26/23

= 256,483 kW.h

= 923 GJ

The total was therefore 1936 GJ.

5.5. PROBLEM AREAS AND SOLUTIONS

5.5.1 FREEZING OF MOISTURE IN PNEUMATIC CONTROLS

Much of the down-time during the early part of the monitoring program was due to seized-up flue gas control dampers. This was caused by the freezing of moisture in the pneumatic controls during periods of cold weather. The problem was solved by installing an air dryer to remove moisture from the compressed air in the control system.

5.5.2 CORROSION OF RECUPERATOR CIRCULATING PUMPS

The water recirculation pumps provided with the recuperator had been expected to be able to withstand acidic solutions. As it turned out, all four pumps were badly damaged by corrosion and had to be replaced after four months of operation. John Thurley Ltd. replaced these with stainless steel pumps, which have operated successfully to date.

No other problems have been encountered since. The recuperator has proven to be very reliable.

6.0 ECONOMIC ANALYSIS

6.1 CAPITAL COST

The capital cost of the project was as follows:

Item	Cost
Recuperator and Controls	$225,000
Installation and Auxiliaries	175,275
Total Installed Cost	$400,275

6.2 NET ANNUAL SAVINGS

The net annual savings are calculated below:

Fuel Savings	$157,010
Less Cost of Electricity for Auxiliary Equipment	(12,000)
Less Cost of Maintenance	(4,300)
Net	$140,710

The components of the above calculation are explained in the following three sections.

6.2.1. FUEL SAVINGS

During the six month monitoring period of October 1982 to March 1983, the fuel savings were estimated to be $89,810, as shown in Table 5.

The second monitoring period was 23 weeks long, and resulted in estimated gas savings of 339,000 m^3. If this period had covered a full 26 weeks the saving would probably have been:

$$= 399{,}000\ m^3 \times 26/23$$
$$= 451{,}000\ m^3$$

During this period the average gas price was 0.149 $\$/m^3$, therefore the cost reduction was:

$$451{,}000\ m^3 \times 0.149\ \$/m^3$$
$$= \$67{,}200$$

The total first year fuel saving was $157,010.

TABLE 5 - FUEL SAVINGS

MONITORING PERIOD - OCTOBER, 1982 - MARCH, 1983

Week Beginning	Fuel Savings	Fuel Price	Cost Savings
	m^3	$/$m^3$	$
October 2	21,200	0.1448	3,070
9	5,900	0.1448	850
16	14,100	0.1448	2,040
23	26,800	0.1451	3,890
30	21,500	0.1451	3,120
November 6	19,100	0.1451	2,770
13	20,800	0.1451	3,020
20	29,500	0.1451	4,280
27	27,100	0.1476	4,000
December 4	25,000	0.1476	3,690
11	21,700	0.1476	3,200
18	19,100	0.1476	2,820
25	17,700	0.1476	2,610
January 1	27,400	0.1416	3,880
8	20,400	0.1416	2,890
15	29,600	0.1416	4,190
22	32,400	0.1416	4,590
29	32,600	0.1416	4,620
February 5	29,100	0.1416	4,120
12	32,400	0.1416	4,590
19	32,600	0.1416	4,620
26	26,300	0.1416	3,720
March 5	24,800	0.1412	3,500
12	23,700	0.1412	3,350
19	25,200	0.1412	3,560
26	20,000	0.1412	2,820
	626,000		89,810

6.2.2 COST OF ELECTRICITY FOR AUXILIARY EQUIPMENT

During the first monitoring period the recuperator required an estimated 1013 GJ of electrical energy at a peak demand of 82.9 kV.A.

At the unit price of 3.453 $/GJ the energy cost was:

= 1013 GJ x 3.453 $/GJ

= $3,500

At the unit price of 5.217 $/kV.A/month the demand cost was:

= 82.9 kV.A x 6 Month x 4.773 $/kV.A/month.

= $2,400

Therefore the total power cost in the first half of the year was $5,900.

Electrical costs averaged 3.793 $/GJ and 5.217 $/kV.A during the second half of the year. For the second half consumption of 923 GJ at 82.9 kV.A the total power cost was approximately $6,100. Therefore the total annual cost was $5,900 + $6,100 = $12,000.

6.2.3 COST OF MAINTENANCE

The first year maintenace costs were as follows:

	Item	Cost
1.	General preventative maintenance	$1,000
2.	Annual shutdown	1,500
3.	Instrumentation calibration	800
4.	Miscellaneous repairs	1,000
	TOTAL	$4,300

6.3 SIMPLE PAYBACK

Based on the capital cost of $400,275 and net annual savings of $140,710 the simple payback of the recuperator is:

$$\frac{\$400,275}{140,710\ \$/yr.} = 2.84 \text{ years}$$

7.0 CONCLUSIONS

The Thurley Direct Contact Heat Recuperator installed at the Winnipeg Packinghouse Plant is recovering the expected amount of heat and has operated without major problems since it was installed in the summer of 1982. Canada Packers is confident that the project will achieve the projected return on investment.

Technically, the recuperator can be applied wherever there is a sufficient balance between steam production and the requirement for low grade heat, such as hot water below 60°C.

The economic viability of the recuperator is largely dependent on the price of fuel. The decision to install one should be based on the payback period of the extra investment over that of a conventional heat recovery system.

APPENDIX A

STEAM SAVINGS FACTOR

A1.0 DERIVATION OF STEAM SAVINGS FACTOR

The heat recovered by the recuperator replaces heat which would have been derived from steam. The reduction in steam consumption can be expressed by:

$$\Delta M_{sr} = K \cdot Q_r \qquad (1)$$

Where: Q_r = heat recovered, GJ (metered)

K = steam savings factor, KG/GJ

ΔM_{sr} = steam saved by recuperator, KG

In order to use equation 1 it is necessary to find an expression for the steam savings factor, K. In order to derive K, it is necessary to consider the change in the water heating process due to the recuperator.

Prior to installation of the recuperator, water was heated by steam injection. The recuperator pre-heats the water to 50°C, which is then heated to the desired temperature by steam injection. Therefore, the recuperator saves steam as follows:

1. It saves some of the live steam used to heat water.
2. It saves the steam used by the de-aerator to heat the make-up for the steam saved in the above item.

The steam saved by the water heating process can be expressed as:

$$\Delta M_{sw} = \frac{M_{hw} \cdot C \, (T_{hw} - T_{cw})}{E_{hw} \, (H_s - C \cdot T_{cw})} \qquad (2)$$

Where: M_{hw} = mass of water heated, KG

T_{hw} = temperature of preheated water leaving the recuperator, °C.

T_{cw} = temperature of cold water entering the recuperator, °C

E_{hw} = efficiency of steam utilization by steam injection water heater

H_s = total enthalpy of steam, KJ/KG

C = specific heat of water, J KG^{-1} K^{-1}

The steam saved by the de-aerator to heat the make-up for ΔMsw can be expressed as:

$$\Delta M_{smu} = \frac{\Delta M_{sw} \cdot C(T_{fw} - T_{mu})}{E_{mu} (H_s - C \cdot T_{fw})} \quad (3)$$

Where: T_{fw} = temperature of feedwater leaving the de-aerator, °C.

T_{mu} = temperature of make-up entering de-aerator, °C.

E_{mu} = efficiency of steam utilization by de-aerator

H_s and C are the same as for equation (2)

The total steam saving is the sum of equations 2 and 3:

$$\Delta M_{sr} = \Delta M_{sw} + \Delta M_{smu} \quad (4)$$

Substituting equation 3 for ΔMsmu above yields:

$$\Delta M_{sr} = \Delta M_{sw} + \frac{\Delta M_{sw} \cdot C(T_{fw} - T_{mu})}{E_{mu} (H_s - C \cdot T_{fw})} \quad (5)$$

Factoring out ΔM_{sw} yields:

$$\Delta M_{sr} = \Delta M_{sw} \left[1 + \frac{C \cdot (T_{fw} - T_{mu})}{E_{mu} (H_s - C \cdot T_{fw})} \right] \quad (6)$$

Substituting equation 2 for ΔM_{sw} above yields:

$$\Delta M_{sr} = \frac{M_{hw} \cdot C\ (T_{hw} - T_{cw})}{E_{hw}\ (H_s - C \cdot T_{cw})} \left[1 + \frac{C \cdot (T_{fw} - T_{mu})}{E_{mu}\ (H_s - C \cdot T_{fw})} \right] \quad (7)$$

At this point it is useful to restate the objective. That is, to find K for:

$$\Delta M_{sr} = K \cdot Q_r \quad (1)$$

Equation 7 (which is equal to equation 1) contains the following term which is equal to Q_r :

$$Q_r = M_{hw} \cdot C\ (T_{hw} - T_{cw}) \quad (8)$$

This term can be divided out to yield the expression for K:

$$K = \frac{1}{E_{hw}\ (H_s - C \cdot T_{cw})} \left[1 + \frac{C \cdot (T_{fw} - T_{mu})}{E_{mu}\ (H_s - C \cdot T_{fw})} \right] \quad (9)$$

A2.0 CALCULATION OF STEAM SAVINGS FACTOR

The numerical value of the steam savings factor, K, used in Table 3 was calculated using equation 9, and the following data and assumptions:

DATA: $C = 4.187$ KJ KG^{-1} K^{-1}

$H_s = 2780.8$ KJ/KG (at steam pressure of 997.6 KPa, ABS)

$T_{cw} = 23.9°C$ (average)

$T_{fw} = 115°C$

$T_{mu} = 23.9°C$ (average)

Assumptions: $E_{hw} = 0.85$

$E_{mu} = 0.90$

$$K = \frac{1}{0.85(2780.8 - 4.187 \times 23.9)} \left[1 + \frac{4.187(115 - 23.9)}{0.90(2780.8 - 4.187 \times 115)} \right]$$

$= 0.0005198$ KG/KJ

$= 0.5198$ t/GJ